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TASTE AND ODOR PRODUCTION BY BLUE-GREEN ALGAE IN RESERVOIRS

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PROGRESS REPORT

PRODUCTION OF TASTE AND ODOR PRODUCING ALGAE IN RESERVOIRS

Division of Water Supply and Pollution Control -

Research and Training Grants Branch

Research Grant WP-334

Report covers the period from June 1, 1962

to September 30, 1964

by

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Salt Lake City, Utah

October 28, 1964

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TASTE AND ODOR PRODUCTION BY BLUE-GREEN ALGAE IN RESERVOIRS

Arden R. Gaufin

A paper presented on June 4, 1964, at the Annual Conference, A. W. A., Toronto, Ontario, by Arden R. Gaufin, Professor of Zoology, University of Utah. This investigation was supported in part by Research Grant WP-334 from the Research Grants Branch, Division of Water Supply and Pollution Control, U. S. P. H. S.

Introduction

The ideal water that every waterworks man desires and every citizen demands is a safe, colorless, odorless, and tasteless water. Waters free from odor and taste nuisances are desirable for drinking and domestic use, industry, shellfish culture, and recreation. Odors and tastes are particularly undesirable in water for drinking and domestic purposes, beverages, dairying, distilling and brewing, and other food processing industries.

Extensive undesirable tastes and odors have occurred frequently during the last few years in many public water supplies using lakes and streams as sources of water. The periodic recurrence of objectionable tastes and odors in these waters has caused much concern to consumers and to water works and health officials. The discharge of industrial and domestic wastes into our water courses has further aggravated the problem.

Most of the obnoxious tastes and odors in drinking water, other than those caused by industrial wastes, are due to organic substances in solution and suspension or to microscopic organisms. The odors caused by

organic matter other than living organisms might be classified as vegetable odors and odors of decomposition. They vary in character in different waters and at different seasons. Many vegetable odors are caused by colloidal vegetable matter. Brown-colored waters invariably have a sweetish vegetable odor, and the intensity of the odor varies with the depth of the color. Both color and odor are due to the presence of certain glucosides, of which tannin is an example, extracted from leaves, grasses, and other vegetation.

The odors of drinking water that are due to the presence of living organisms are common in occurrence, often very offensive in nature, and may affect large bodies of water. At one time it was thought that it was only by decay that the organisms became odoriferous. It is now well-established that many living organisms have an odor that is natural and peculiar to them, just as many flowers have their own characteristic odors. It has been found that in most cases the odor is produced by compounds analogous to the essential oils. The oils are produced during the growth of the organisms, and in many genera the oil globules may be seen if the organisms are examined under a sufficiently high-powered microscope. Microorganisms in water that have been incriminated in taste and odor production include the protozoa, bacteria, actinomycetes, molds, and algae. The last group is particularly important in water supplies.

The degree to which a body of water can support a dense "bloom" of an alga and becomes highly odoriferous depends on the specific environmental requirements of the alga, including its nutritional needs. In their growth, algae utilize the mineral nutrients that have come from the land as well as carbon dioxide from the air or that released in the

decay of organic matter. Nutrients that support algal growth in lakes and reservoirs originate in the surrounding drainage area and enter with the runoff. If the soil is fertile, nutrients for algae are likely to be abundant.

Natural drainage or runoff waters contain varying quantities of nutrients depending upon their source.[1] These natural nutrient concentrations become altered through man's multipurpose usage of land and water. This alteration often results in an increase in the phosphorus and nitrogen content of the drainage water. An increase in the nutrient content of the water may result in such an increased algal productivity that normal water uses may be jeopardized. In lakes polluted with sewage, algal blooms may become particularly frequent and objectionable. Sawyer, in his study of Wisconsin lakes (1947), reported that large phytoplankton blooms may be supported when phosphorus concentrations are in or above the range of 10 p.p.b. PO_4P and nitrogen concentrations are above 300 p.p.b.NO_3N.[2] Hutchinson (1957) reported mean nitrate nitrogen values of 50 to 86 p.p.b. in three Wisconsin lakes that produce regular nuisance blooms of algae.[3] Nuisance algal blooms were observed (Sylvester and Anderson, 1960) to commence in Seattle's Green Lake when nitrate nitrogen levels were generally above 20 p.p.b. and soluble phosphorus was greater than 10 p.p.b.[4]

Characteristics of Reservoirs

Since 1930 the federal, state, and a few local governments have been engaged in the construction of numerous large, multipurpose reservoirs.[5] Many of the reservoirs constructed in the western states have presented unusual limnological problems, especially with reference to

silting, fish management, and algal nuisances. Many of the reservoirs constructed along the larger streams in the west have developed a heavy growth of blue-green algae late in each summer, especially for several years following filling. Reservoirs vary in a number of physical details from natural and/or glaciated lakes that are located in river systems, thus resulting in a number of different limnological problems.[6]

Inlets and outlets of glaciated lakes are near the surface, but water may leave a reservoir at one or several depths. The lowest depression in a natural lake may occur anywhere in its basin, but maximum depth of a reservoir is usually near the dam. A reservoir bottom has a regular slope from head to tail that was established by the river before damming. The basins of glaciated lakes were scooped out below river level, and non-uniformity of bottom slope is the usual case.

Reservoirs often develop typical thermal stratification, with formation of epilimnion, metalimnion, and hypolimnion. However, they are subject to periodic, intermittent, or even prolonged entrance of large quantities of water that differ markedly from any water stratum in them. These invading flows sink or rise to the proper density level and then move on down-reservoir as sharply defined layers that pass over the surface or wedge their way between or under existing water strata. These density currents continue until they break against the dam, and then come to rest and form additional water strata. Since they often carry large silt loads, density flows are responsible for heavy siltation that affects large areas of reservoir bottom. During overturns or where there is considerable wind action, this deposited silt may be stirred up, greatly increasing the turbidity of the entire reservoir.

Glaciated lakes normally begin as oligotrophic bodies of water and develop to a eutrophic condition over many years. Increases in productivity are gradually brought about by contributions of organic material originating in their drainage basins. Reservoirs, on the other hand, inundate rich bottom lands and fertile topsoils on river slopes and normally begin their lives with a high productivity potential, since mineral nutrients and organic materials are leached from these soils. Reservoirs tend to suffer productivity declines with passage of time and may never regain their initial productivity level unless man interferes.

Deer Creek Reservoir

The author, since 1954, has studied several reservoirs in Utah, Colorado, and Wyoming, and this paper deals particularly with two of them, Deer Creek Reservoir in Utah and Lake Viva Naughton, Wyoming.

Deer Creek Reservoir is located at the southwest end of Heber Valley in Wasatch County, Utah, about 35 miles southeast of Salt Lake City. When filled to capacity, the reservoir is about seven miles long by three-quarters mile wide. At maximum pool stage, it has a capacity of nearly 150,000 acre feet. Although the maximum depth of the reservoir is over 120 feet, there are extensive shallow areas in the upper half, and when completely filled, 14% of the reservoir is less than 10 feet deep. The principal source of water for the impoundment is the Provo River, which has its head waters in the Uintah Mountains to the east of the reservoir. Water from the reservoir constitutes the chief source of culinary water for Salt Lake City.

Construction on the reservoir began in May, 1938, and it was completed in the fall of 1941. The reservoir is subjected to considerable fertilization

through return flow irrigation; drainage from pastures, farm yards, and recreation areas; and from sewage effluent from the Heber City primary treatment plant. During the summer the plant is often by-passed, and raw sewage from the city, a town of nearly 10,000 people, is emptied into Spring Creek at a point two miles above the reservoir. Because of the high organic content of the streams entering Deer Creek and the inevitable rise in temperature caused by the impoundment, algal blooms soon became prevalent following construction.

No intensive study of the reservoir or algal control program was undertaken until the summer of 1954. The productivity of the reservoir had increased by that time to the point where an algal control program became a necessity to control the frequent algal blooms that developed.

Although no limnological studies were conducted immediately following the completion of the reservoir, observations made by the residents of the area indicate that the inundation of terrestrial vegetation resulted in the production of large quantities of organic nutrients, which contributed to extensive blooms of blue-green algae during the early life of the impoundment. Since 1954 plankton distribution has varied seasonally, but in the winter months diatoms, such as Asterionella formosa and Stephanodiscus sp., have predominated below the ice. During the summer months Fragilaria pulchella has been the dominant form in the lower, deeper section of the reservoir, but a blue-green alga, Anabaena flos-aquae, has produced the most obnoxious tastes and odors.[7] This species has appeared in the upper, shallower end of the reservoir by mid-July every summer since 1954. During several summers, as in 1959, this form appeared in such large numbers as to produce a condition where the surface waters

had a pea-soup consistency. Inasmuch as Anabaena flos-aquae has the ability to fix nitrogen, the blooms of this form were always followed by a great increase in green algae, which multiplied in response to the greatly increased nitrate concentration in the water.[8]

Control of Anabaena and Fragilaria pulchella has been successfully accomplished by the use of copper sulphate, but treatment has been costly and, as might be expected, has not prevented the accumulation of organic matter at the bottom of the reservoir. This decaying material has produced hydrogen sulfide below the thermocline, and during the autumnal overturn for several years produced a very unpalatable condition in the water supplied to Salt Lake City.

Lake Viva Naughton

An opportunity to study the immediate effects of stream impoundment on the water quality in a reservoir was presented during the summer of 1962 by the construction of Lake Viva Naughton, Wyoming, by the Utah Power and Light Company. This reservoir is located eight miles northwest of Kemmerer, Wyoming, and was formed by the construction of a dam on Ham's Fork River, a tributary of the Green River. The reservoir, when filled to capacity, is approximately five miles long, one mile wide, and 45 feet deep at its deepest point. The area covered by the impoundment was rich meadow land with an abundant growth of willows along the stream. The area was used as grazing land for cattle and sheep and was well-fertilized by animal wastes. The drainage area above the reservoir is used for a similar purpose, and the water supplying the reservoir is heavily organically enriched by sheep and cattle manure.

The Kemmerer City Reservoir is located approximately ½ mile below Lake Viva Naughton, and it serves as the chief source of culinary water for the city of Kemmerer. The phytoplankton population in this reservoir during the summer of 1962 consisted chiefly of diatoms but changed considerably in 1963 due to the "seeding" effect of Lake Viva Naughton above.

A plankton sampling program was initiated on these two reservoirs in July, 1962, and extended through October. It was continued from May through October, 1963. Fifty to seventy-five percent of the organisms encountered in samples taken from both reservoirs during June and most of July, 1963, belonged to the genus Asterionella, a diatom. Aphanizomenon flos-aquae, a blue-green alga, appeared in samples taken in late July, both in 1962 and 1963, and dominated the population through October. From the time of its appearance until early November, 1962, and through most of August, 1963, Aphanizomenon flos-aquae was two to three times as abundant in Lake Viva Naughton as in Kemmerer City Reservoir, but during September through October, 1963, it became more concentrated in the latter reservoir. This downstream seeding seriously aggravated the already bad taste and odor problem in the Kemmerer City culinary water supply.

An average of 270,000 A. flos-aquae per liter was present in samples taken from Lake Viva Naughton on July 25. The number increased to a peak population of 1,827,000 per liter on August 30 and gradually declined to 59,000 per liter two months later. By contrast the species averaged 54,000 per liter in Kemmerer Reservoir on July 25, 1,231,000 per liter on August 30, and 1,078,000 per liter on October 26.

The presence of Aphanizomenon flos-aquae in such large numbers resulted in the production of a very foul "pigpen" odor in the water wherever the alga was concentrated. The odor developed from the products of decomposition as the algal cells died and disintegrated. During August through October both years, the shoreline of the reservoirs was covered with a slimy, blue-green layer of dead and decaying A. flos-aquae, and the odor was unmistakable.

Aphanizomenon flos-aquae consists of parallel filaments tapering at both ends and united in bundles or flakes to form microscopic colonies of few or hundreds of plants. The plant is a frequent component of water blooms and in favorable habitats may become super-abundant, as in these two reservoirs. Hard-water lakes in which there are a high nitrogen content and an adequate supply of carbon dioxide are particularly conducive to the growth of this plant. The cells have false vacuoles, which permit the filaments to float high in the water where they form masses that are sometimes a square foot in extent, as occurred in Lake Viva Naughton. Either alone or in accompaniment with other blue-green algae, such as Anabaena, this plant is not infrequently responsible for oxygen depletion in small lakes and bays, resulting in great loss of fish. The species may remain alive all winter in the vegetative state, sometimes thriving under the ice.

Aside from their role in the production of tastes and odors in the Kemmerer City water supply, the large numbers of algae that have been present in Lake Viva Naughton and Kemmerer City Reservoir during the last two years, if allowed to continue, could produce a more serious impact. Interference by algae with chemical treatment of water can result

from changes the algae cause in pH, alkalinity, total hardness, and dissolved oxygen of the raw water, or by their increasing the organic content carried by the water.

There are a number of records of acute and often fatal poisoning of livestock where the animals have been drinking from ponds containing dense algal blooms. Both Aphanizomenon flos-aquae and Anabaena have been involved in such poisoning of animals. There is also the possibility that the disintegration of large amounts of blue-green algae such as these forms may produce toxic substances which may be the cause of gastrointestinal disturbances in man.

No treatment of either reservoir to control the Aphanizomenon blooms was undertaken during the two years because of lack of facilities. Due to the high alkalinity of the water, a much higher concentration of copper sulfate than that ordinarily used may be necessary to bring about effective control in the future.

Summary

Most of the obnoxious tastes and odors in drinking water are due to organic substances in solution and suspension or to microscopic organisms. Microorganisms in water that have been incriminated in taste and odor production include the protozoa, bacteria, actinomycetes, and algae. The last group is of particular importance in water supplies. The degree to which a body of water can support an algal bloom and becomes highly odoriferous depends to a large extent on the nutritional requirements of the alga. Nitrate nitrogen concentrations above 50 p.p.b. and soluble phosphorus levels greater than 10 p.p.b. are reported as

being conducive to the production of nuisance blooms of algae (1, 2, 3).

Many of the multipurpose reservoirs that have been constructed during the last few years in the western states have produced very objectionable algal blooms early in their history. Most of these reservoirs have inundated rich bottom lands and fertile topsoils on river slopes and have had a high productivity potential because of the abundant mineral nutrients and organic materials that were covered. Limnological studies of Deer Creek Reservoir, Utah, and Lake Viva Naughton, Wyoming, that have been conducted by the author well illustrate the effects of organic enrichment on plankton production.

Anabaena flos-aquae, a blue-green alga, has appeared in the upper, shallow end of Deer Creek Reservoir by mid-July every summer since 1954. During several summers, as in 1959, it appeared in such large numbers as to produce a condition where the surface waters had a pea-soup consistency and a strong fishy odor. Inasmuch as this species has the ability to fix nitrogen, blooms of this form were always followed by an increase in green algae, which multiplied in response to the greatly increased nitrate concentration in the water.

Another blue-green alga, Aphanizomenon flos-aquae, appeared by mid-July, 1962, in bloom proportions in Lake Viva Naughton, only two months after the reservoir was filled for the first time. From 270,000 to 1,827,000 specimens per liter were present in samples taken from mid-July to late October during 1962 and 1963. The presence of Aphanizomenon flos-aquae in such large numbers resulted in the production of a very foul "pigpen-like" odor in the water wherever the alga was concentrated.

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LIMNOLOGICAL SURVEY OF LAKE VIVA NAUGHTON AND KEMMERER RESERVOIR, KEMMERER WYOMING

1963

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Limnological studies of Lake Viva Naughton and Kemmerer Reservoir, Kemmerer, Wyoming, were initiated on June 7, 1963, and continued throughout the summer and autumn to October 26, 1963. Participating in the studies were Hugh Crutchfield of the Utah Power and Light Company and Arden R. Gaufin, William Funk, and Jay Richardson of the University of Utah. The objectives of the studies were as follows: (1) to determine the kinds of plankton in the reservoirs and the relative numbers of each; (2) to determine the potentialities of such plankton in the production of tastes and odors in the reservoir; (3) to determine the factors which might be conducive to the production of plankton blooms; (4) to ascertain what procedures might be advisable for controlling or preventing the development of obnoxious tastes and odors in the reservoir; (5) to determine the possible effects of such plankton production on the Kemmerer City water supply; and (6) to collect comparative data to that taken during 1962 as a possible basis for predicting future trends in the reservoirs.

Water samples were collected from nine different areas in Lake Viva Naughton, from five areas in Kemmerer Reservoir, from the pumping station on Ham's Fork Creek, and from the settling basin at the power plant on 20 different sampling dates. These samples were analyzed for plankton

and other biota that were present. Five-hundred c.c. samples of water were centrifuged by means of a Foerst plankton centrifuge to concentrate any plankton present to a 10 c.c. sample. A 1 c.c. sample of the concentrate in each case was examined under a compound microscope and plankton counts made by means of a Sedgwick Rafter slide and Whipple disc. All of the plankton encountered in 10 fields (.01 c.c.) of the slide were identified to genus and counted for comparative purposes. A summary of the plankton collected on each date is presented in the accompanying tables.

Fifty to seventy-five per cent of the organisms encountered in samples taken from both reservoirs during June and most of July belonged to the genus, Asterionella, a diatom. Aphanizomenon flos-aquae, a blue-green algae, appeared in samples taken on July 25, 1963, and dominated the population from that date through October. From ninety to ninety-nine per cent of the plankton encountered in thirteen sets of samples taken during that period belonged to this species. From the time of its appearance through most of August, Aphanizomenon flos-aquae was two to three times as abundant in Lake Viva Naughton as in Kemmerer City Reservoir, but during September through October it became more concentrated in the latter reservoir.

An average of 270,000 A. flos-aquae per liter was present in samples taken from Lake Viva Naughton on July 25. The number increased to a peak population of 1,827,000 per liter on August 30 and gradually declined to 59,000 per liter two months later. By contrast this species averaged 54,000 per liter in Kemmerer Reservoir on July 25, 1,231,000 per liter on August 30, and 1,078,000 per liter on October 26.

In comparison with the summer of 1962, A. flos-aquae was much more

persistent in its occurrence in 1963 than during the preceding summer. In 1962 it disappeared completely during the month of August but again appeared in bloom proportions during September and October. It also appeared much earlier in Kemmerer Reservoir in 1963, demonstrating the very definite seeding effect of the population that built up in Lake Viva Naughton.

The presence of Aphanizomenon flos-aquae in such large numbers indicates a condition highly conducive to the production of tastes and odors in the water leaving the reservoir. This species is capable of producing very foul "pigpen" odors in water. The foul odor develops from the products of decomposition as the algae begin to die off in large numbers. During August through October the shoreline of the reservoirs was covered with a slimy blue-green layer of dead and decaying A. flos-aquae, and the odor was unmistakable wherever the algae were concentrated.

Aphanizomenon flos-aquae consists of parallel filaments, tapering at both ends, united in bundles or flakes to form microscopic colonies of few or hundreds of plants. The plant is a frequent component of water blooms and in favorable habitats may become super-abundant. Hard water lakes in which there is a high nitrogen content and an adequate supply of carbon dioxide may become biologically unbalanced by excessive growth of this plant. The cells have false vacuoles which permit the filaments to float high in the water where they form masses that are sometimes a square foot in extent, as occurred in Lake Viva Naughton during September and October. Either alone or in accompaniment with other blue-green algae such as Anabaena, this plant is not infrequently responsible for oxygen depletion in small lakes and bays, resulting in great loss of

fish. The occurrence of the species is consistently related to hard water lakes, high pH, and a high nitrogen and bicarbonate content such as exist in Lake Viva Naughton. The species may remain alive all winter in the vegetative state, sometimes thriving under the ice.

The diatoms encountered in both reservoirs, in addition to the extensive beds of higher aquatic plants consisting of Potamogeton, Ceratophyllum, and Najas, could also produce tastes and odors. Such forms as Asterionella, Fragilaria, and Stephanodiscus have all been incriminated in taste and odor production in numerous water supplies throughout the country as well as being responsible for clogging filters in water treatment plants. Asterionella is considered one of the worst offenders among the diatoms, having a characteristic aromatic geranium-like odor that changes to fishy when the alga is present in large numbers.

Aside from their role in the production of tastes and odors in the Kemmerer City water supply, the large numbers of algae that have been present in Lake Viva Naughton and Kemmerer Reservoir during the last two years, if allowed to continue, could produce a more serious impact. Interference by algae with the chemical treatment of water can result by changes they cause in pH, alkalinity, total hardness, and dissolved oxygen of the raw water, or by their increasing the organic content carried by the water.

Where clarification of water is necessary by means of coagulation and sedimentation, large numbers of diatoms in the raw water may cause problems. Asterionella and Synedra, in particular, have given difficulty by inhibiting proper floc formation. Daily blooming of algae in reservoirs

frequently induces the formation of a weak floc during coagulation in treatment plants and allows appreciable amounts of undesired substances to remain in the water and to pass through the sand filters into the finished water. The blooming of the algae may cause the pH of the raw water to rise from 7.0 to 9.6 in a few hours as it did several times in Kemmerer Reservoir during the summer. A high pH causes a poor floc to be formed when alum is added.

Illness in man and animals has been attributed to both marine and fresh water algae. Unexplained outbreaks of gastroenteritis involving thousands of people have been reported in areas where extensive algal blooms were present. There is a possibility that the disintegration of large amounts of blue-green algae such as Aphanizomenon flos-aquae may produce toxic substances which may be the cause of gastro-intestinal disturbances in man.

There are many records of acute and often fatal poisoning of livestock where the animals have been drinking from ponds containing dense algal blooms. Both Aphanizomenon flos-aquae and Anabaena have been involved in such poisoning of animals.

Fish kills in fresh water lakes and reservoirs have often been blamed on algal blooms. When there is a heavy algal growth, a reduction in the amount of sunlight due to weather conditions will reduce the photosynthetic activity of the algae. With insufficient oxygen being produced the algae are forced to use the oxygen stored in the water for respiration. If this condition should exist for any length of time, the water could lose most of its oxygen, causing fish to die of oxygen suffocation. The oxygen content in the southeastern bay of Lake Viva

Naughton in early October dropped to 1.5 p.p.m., which could have caused a fish kill if the fish hadn't been able to move to the open sections of the lake where the oxygen content was higher.

A sizeable fish kill occurred under similar circumstances in Flaming Gorge Reservoir during late October. Either low dissolved oxygen concentrations or toxic products produced by decaying Aphanizomenon flos-aquae were responsible for the loss of thousands of fish. Such a loss could easily occur in Lake Viva Naughton or Kemmerer Reservoir in the future unless steps are taken to control the algal growths.

Water samples from the surface, taken at the upper and lower ends of both reservoirs and from the outlet of Lake Viva Naughton, were analyzed for temperature, dissolved oxygen, carbon dioxide, calcium carbonate, and calcium bicarbonate. The results are given in the accompanying table.

The results indicated chemical but not thermal stratification in Lake Viva Naughton just above the dam during August, September, and October and the presence of bicarbonates in sufficient quantity to be conducive to high productivity of plankton. Greatly increased photosynthetic activity by the dense growth of plankton present in both reservoirs had the combined effect of softening the water by carbonate precipitation and greatly increasing the pH and dissolved oxygen content during the daytime. The reverse was true at night. Nitrate analyses made by Hall Laboratories of water from Ham's Fork Creek also indicate sufficient dissolved nitrates to encourage plankton blooms.

The plankton encountered in both reservoirs, as well as the higher aquatic plants occurring in the Kemmerer Reservoir, could be controlled by the use of copper sulphate in sufficient concentrations, if applied

at the proper time. Concentrations of 1 p.p.m. are ordinarily effective in bringing about control, but due to the high alkalinity a higher concentration of copper sulphate may be necessary. This may be necessitated because of the tendency of excessive bicarbonates to react with copper sulphate in hard water.

No treatment of either reservoir was undertaken during the year because of lack of facilities. The bloom of Aphanizomenon flos-aquae was so concentrated during most of the summer and fall that treating and a subsequent rapid die-off of the cells would certainly have resulted in considerable depletion of oxygen. The degree of depletion may have been sufficient to have killed numerous fish, especially in the shallow areas of the reservoir, and thus resulted in more damage than benefit. Treatment of the water in the future is advisable but should be carried out before such peak plankton populations as occurred this past summer are reached.

DOMINANT PLANKTON
AVERAGE NUMBER
LAKE VIVA NAUGHTON - KEMMERER RESERVOIR

1963

Date	Plankton	Lake Viva Naughton		Kemmerer Reservoir	
		Av. No. per .01 c.c. (Concentrate)	Av. No. per Liter	Av. No. per .01 c.c. (Concentrate)	Av. No. per Liter
6/7/63	Asterionella Spirogyra	180	180,000	448	448,000
6/12/63	Asterionella	104	104,000	98	98,000
6/20/63	Asterionella Oscillatoria	41	41,000	43	43,000
6/28/63	Asterionella	316	316,000	26	26,000
7/3/63	Asterionella Diatoma	241	241,000	462	462,000
7/13/63	Coelastrum Asterionella	17	17,000	57	57,000
7/18/63	Asterionella Diatoma	20	20,000	12	12,000
7/25/63	Aphanizomenon	270	270,000	54	54,000
7/31/63	Aphanizomenon	317	317,000	131	131,000
8/8/63	Aphanizomenon	868	868,000	498	498,000
8/15/63	Aphanizomenon	406	406,000	111	111,000
8/24/63	Aphanizomenon	414	414,000	358	358,000
8/30/63	Aphanizomenon	1,827	1,827,000	1,231	1,231,000
9/9/63	Aphanizomenon	435	435,000		
9/17/63	Aphanizomenon	752	752,000	506	506,000
9/25/63	Aphanizomenon	653	653,000	922	922,000
10/3/63	Aphanizomenon	275	275,000	313	313,000
10/10/63	Aphanizomenon	703	703,000	673	673,000
10/18/63	Aphanizomenon	719	719,000	1,355	1,355,000
10/26/63	Aphanizomenon	59	59,000	1,078	1,078,000

LAKE VIVA NAUGHTON - KEMMERER RESERVOIR

KEMMERER, WYOMING

Chemical Analyses - 1963

Date	Water Temp.	D.O.	CO_2	pH	Carbonates	Bicarbonates
6/7/63						
N.W. Bay	50°	8.3	0.0	8.1	0.0	152
Buoys - Surface	53°	9.6	0.0	8.1	0.0	153
Buoys - Bottom	47°	1.7	1.5	7.7	0.0	155
Kemmerer - W. Dam	56°	9.1	0.0	8.1	0.0	156
6/12/63						
S.E. Bay	59°	9.4	0.0	8.4	0.0	156
Stream Inlet	59°	10.3	0.0	8.4	0.0	164
Buoys - Surface	59°	8.1	0.0	8.3	0.0	155
Buoys - Bottom	57°	2.1	2.0	7.7	0.0	154
Kemmerer - N.E.	64°	7.0	0.0	8.1	0.0	155
Kemmerer - E. Dam	63°	7.0	0.0	8.1	0.0	155
Holding Pond	63°	9.1	0.0	8.4	12.0	140
6/20/63						
S.E. Bay	62°	8.0	0.0	8.3	0.0	170
Stream Inlet	58°	7.6	0.0	8.3	2.0	174
Center - Lake	60°	10.0	0.0	8.3	3.5	173
Buoys - Surface	62°	8.1	0.0	8.3	1.0	203
Buoys - Bottom	49.5°	1.4	0.0	7.5	4.0	194
Kemmerer - East	62°	12.2	0.0	6.9	3.7	302
Kemmerer - E. Dam	62°	8.6	0.0	8.3	1.2	170
Holding Pond	61°	8.0	0.0	8.4	3.0	160
6/28/63						
S.E. Bay	59.5°	10.0	0.0	8.4	8.0	167
Buoys - Surface	59.5°	8.4	0.0	8.4	10.0	164
Kemmerer - East	62.5°	7.7	0.0	8.5	8.0	177
Ham's Fork	62.5°	7.7	0.0	8.5	8.0	177
Holding Pond	63.5°	9.3	0.0	8.4	5.0	176
7/12/63						
N.W. Bay	62°	5.4	0.0	8.3	4.0	191
Center - Lake	62°	8.7	0.0	8.1	6.0	187
Buoys - Surface	62°	9.0	0.0	8.5	6.0	190
Buoys - Bottom	58°	3.6	2.0	7.7	0.0	196
Kemmerer - N.E.	72°	9.1	0.0	8.5	8.0	184
Kemmerer - E. Dam	64°	9.2	0.0	8.5	11.0	184
Ham's Fork	64°	8.0	0.0	8.5	5.0	133
Holding Pond	66°	8.6	0.0	8.5	2.0	164

LAKE VIVA NAUGHTON - KEMMERER RESERVOIR

KEMMERER, WYOMING

Chemical Analyses - 1963

Date	Water Temp.	D.O.	CO_2	pH	Carbonates	Bicarbonates
7/18/63						
S.E. Bay	63°	8.2	0.0	8.6	13.0	171
East Ranch	62.5°	7.2	0.0	8.4	5.0	181
Buoys - Surface	62°	9.5	0.0	8.5	7.0	172
Buoys - Bottom	55°	5.8	10.0	7.7	0.0	178
Holding Pond	62°	9.1	0.0	9.1	26.0	150
7/25/63						
S.E. Bay	64°	11.0	0.0	8.4	8.0	145
7/31/63						
S.E. Bay	64°	6.4	0.0	8.5	6.0	171
Buoys - Surface	64°	11.7	0.0	8.5	16.0	149
Buoys - Bottom	61°	4.5	0.0	7.7	0.0	204
Kemmerer - E. Dam	64°	10.2	0.0	8.5	6.0	152
8/8/63						
S.E. Bay	68°	12.1	0.0	9.1	13.0	129
Stream Inlet	67°	9.2	0.0	8.7	14.0	150
Buoys - Surface	68°	12.5	0.0	9.3	22.0	104
Buoys - Bottom	65°	1.4	6.0	7.9	0.0	206
8/15/63						
Stream Inlet	66°	9.4	0.0	8.5	16.0	145
Buoys - Surface	66°	15.9	0.0	8.8	20.0	138
Buoys - Bottom	60°	1.3	7.0	7.0	0.0	195
Kemmerer - N.E.	69°	9.8	0.0	9.1	53.0	109
Holding Pond	70°	9.2	0.0	9.3	48.0	52
8/24/63						
S.E. Bay	59°	10.2	0.0	8.5	6.0	130
Stream Inlet	61°	8.1	0.0	8.5	4.0	190
Buoys - Surface	60°	10.5	0.0	8.9	19.0	125
Buoys - Bottom	59°	1.8	6.0	7.5	0.0	187
Kemmerer - N.E.	69°	8.5	0.0	9.0	46.0	111

LAKE VIVA NAUGHTON - KEMMERER RESERVOIR

KEMMERER, WYOMING

Chemical Analyses - 1963

Date	Water Temp.	D.O.	CO_2	pH	Carbonates	Bicarbonates
9/9/63						
N.W. Bay	63°	3.4	0.0	7.0	0.0	186
Buoys - Surface	66°	16.3	0.0	9.3	1.8	107
Buoys - Bottom	61°	2.4	3.3	7.9	0.0	186
Kemmerer Dam	63°	14.0	0.0	7.9	15.0	45
9/13/63						
S.E. Bay	55°	10.0	0.0	7.0	10.0	70
Buoys - Surface	57°	5.0	0.0	8.3	3.0	97
Buoys - Bottom	58°	5.4	0.0	8.5	0.0	85
9/25/63						
S.E. Bay	60°	6.5	0.0	7.8	0.0	64
E. of Ranch	60°	7.0	0.0	7.9	0.0	90
Buoys - Surface	62°	3.5	0.0	7.9	4.0	85
Buoys - Bottom	62°	1.0	2.5	7.4	0.0	94
10/3/63						
S. E. Bay	58°	6.3	0.0	7.8	0.0	91
Buoys - Surface	59°	6.1	0.0	7.8	0.0	93
Buoys - Bottom	51°	2.3	2.0	7.6	0.0	87
10/10/63						
S.E. Bay	54°	1.5	25.0	7.7	0.0	112
N.W. Bay	56°	9.8	0.0	8.3	14.0	124
Buoys - Surface	55°	5.0	0.0	7.8	5.0	140
Buoys - Bottom	54°	5.0	1.0	7.7	0.0	140
Kemmerer - East	59°	15.0	0.0	8.4	44.0	66
10/17/63						
S.E. Bay	53°	4.1	2.0	7.7	0.0	146
Buoys - Surface	53°	4.8	1.0	7.7	0.0	145
Buoys - Bottom	52°	4.9	0.0	7.7	0.0	142
Kemmerer - East	53°	6.2	0.0	8.0	0.0	145
Kemmerer - Dam	53°	13.2	0.0	9.0	16.0	97
10/25/63						
S.E. Bay	49°	4.5	4.0	7.9	0.0	181
N.W. Bay	49°	6.8	8.0	7.9	0.0	153
Buoys - Surface	49°	5.3	6.0	7.8	0.0	160
Buoys - Bottom	49°	3.3	9.0	7.8	0.0	177

PLANKTON SAMPLING PROGRAM

LAKE VIVA NAUGHTON

Kemmerer, Wyoming

1964

Plankton sampling operations were initiated as soon as weather conditions permitted in the spring of 1964. Samples were collected twice in May to determine the ecological conditions characteristic of the spring period.

Regular sampling began in June and was continued through September on a weekly basis. Samples were also taken during October and early November but only on a three to four week basis.

Water samples were collected on each date from 8-12 different areas in Lake Viva Naughton, from 3-6 different areas in Kemmerer Reservoir, from Ham's Fork Creek at the Utah Power and Light Pumping Station, and from the settling basin at the steam plant. The samples were analyzed for plankton and other biota that were present.

In addition to the plankton determinations, water samples from the inlet and outlet of each reservoir and from Ham's Fork Creek were analyzed chemically for dissolved oxygen (D.O.), carbon dioxide, pH, carbonates, bicarbonates, nitrates, and phosphates.

As part of a research program being conducted on Deer Creek Reservoir in Utah, and being supported in part by a grant from the U. S. Public Health Service, studies to determine photosynthetic rates and gross productivity were also conducted in Lake Viva Naughton. Light-and-dark-bottle and carbon-14 uptake studies were conducted in both reservoirs to help determine the factors most important in producing plankton blooms and tastes and odors resulting from such blooms.